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Human Kinetics
ORIGINAL RESEARCH

The Effect of Exercise Training on Total Daily Energy Expenditure and Body Composition in Weight-Stable Adults: A Randomized, Controlled Trial

Gregory A. Hand, Robin P. Shook, Daniel P. O'Connor, Madison M. Kindred, Sarah Schumacher, Clemens Drenowatz, Amanda E. Paluch, Stephanie Burgess, John E. Blundell, and Steven N. Blair

Background: The present study examined, among weight-stable overweight or obese adults, the effect of increasing doses of exercise energy expenditure (EEex) on changes in total daily energy expenditure (TDEE), total body energy stores, and body composition. **Methods**: Healthy, sedentary overweight/obese young adults were randomized to one of 3 groups for a period of 26 weeks: moderate-exercise (EEex goal of 17.5 kcal/kg/wk), high-exercise (EEex goal of 35 kcal/kg/wk), or observation group. Individuals maintained body weight within 3% of baseline. Pre/postphysical activity between-group measurements included body composition, calculated energy intake, TDEE, energy stores, and resting metabolic rate. **Results**: Sixty weight-stable individuals completed the protocols. Exercise groups increased EEex in a stepwise manner compared with the observation group ($P < .001$). There was no group effect on changes in TDEE, energy intake, fat-free mass, or resting metabolic rate. Fat mass and energy stores decreased among the females in the high-exercise group ($P = .007$). **Conclusions**: The increase in EEex did not result in an equivalent increase in TDEE. There was a sex difference in the relationship among energy balance components. These results suggest a weight-independent compensatory response to exercise training with potentially a sex-specific adjustment in body composition.

Keywords: diet, energy intake, energy stores, exercise compensation

Exercise-induced weight loss is commonly less than that predicted using weight loss models.[1] These models are usually based on the relationship of energy intake and energy expenditure (energy balance) over time. However, there are a number of common assumptions that are made when applying an exercise intervention as part of a program for weight loss. Among these assumptions are (1) that energy expenditure is additive such that increasing exercise energy expenditure (EEex) will result in a proportional increase in total daily energy expenditure (TDEE) and (2) that increasing energy expenditure does not elicit a proportional increase in energy intake. However, it is clear that the components of energy balance—energy intake, expenditure, and stores—are dynamic and interrelated.[2] And the amount of energy expenditure, as well as weight change incurred during an exercise intervention, increases the complexity of the relationships among eating behavior, daily activity, and body composition.[3–7]

A number of research groups have examined the relationship between changes in EEex and TDEE. A major interest in bioenergetics research is the potential compensatory response by which an increase in EEex would elicit a reduction in non-EEex, resulting in no change in TDEE. The literature on the effect of EEex on TDEE has been inconsistent with a compensatory response shown in some,[8–10] but not all,[11–13] studies with compensation more likely in older individuals. There are few prospective, dose–response studies that have examined the interaction of the primary determinants of energy balance (the relationship among energy intake, expenditure, and stores) and specifically determining if there is a compensatory response during an exercise intervention while intentionally maintaining body weight.[14,15] In the present study, overweight and obese young adults participated in a 26-week exercise intervention while maintaining their body weight at baseline levels in a study designed to examine the effects of different doses of exercise-related energy expenditure on TDEE and body composition and energy stores.

Hand is with the Department of Epidemiology, West Virginia University, Morgantown, WV, USA. Shook is with the Department of Pediatrics, Children's Mercy, Kansas City, MO, USA. O'Connor is with the Department of Health and Human Performance, University of Houston, Houston, TX, USA. Kindred is with the Department of Kinesiology, Augusta University, Augusta, GA, USA. Drenowatz is with the Division of Physical Education, University of Education Upper Austria, Linz, Austria. Paluch is with the Department of Kinesiology, University of Massachusetts, Amherst, MA, USA. Burgess is with the College of Nursing, University of South Carolina, Columbia, SC, USA. Blundell is with the Institute of Psychological Sciences, University of Leeds, Leeds, United Kingdom. Schumacher and Blair are with the Department of Exercise Science, University of South Carolina, Columbia, SC, USA. Blair is also with the Department of Epidemiology & Biostatistics, University of South Carolina, Columbia, SC, USA. Hand (gahand@hsc.wvu.edu) is corresponding author.

Methods

Participant Recruitment

Sedentary men and women aged 21 to 45 years with a body mass index (BMI) of 25 to 35 kg/m^2 were recruited. Inclusion and exclusion criteria (Table 1) were designed to select healthy individuals with no major acute or chronic conditions, no recent major changes in health behaviors, and weight change of <2.27 kg in the previous year. The study protocol was approved by the University of South Carolina Institutional Review Board and individuals signed informed consent. The study was registered at ClinicalTrials.gov (ID #NCT01736098).

Participant Flow

The study followed individuals for a period of 7 months with a 26-week training intervention. Table 2 illustrates the data collection

Table 1 Inclusion/Exclusion Criteria

Inclusion criteria	Exclusion criteria
• Body mass index: 25–35 kg/m^2	• Currently participating in structured exercise (3 times per week for the past 6 mo for at least 20 min at a time) based on self-report • >7000 steps per day and >10 min vigorous physical activity during 3-d run-in using SenseWear activity monitor • Planning to participate or currently participating in a weight loss intervention or exercise program
• 21–45 y of age	• Planning to have weight loss surgery
• Fasting plasma glucose <126 mg/dL	• Weight change >5 lb in last 12 mo
• Current medications must have been prescribed for 3 or more months and stable • Internet access (home or other; agreement by participant that they will comply with the extent of Internet use required). We are experienced with using Internet interventions and are aware that we must be certain that participants have regular Internet access and have the ability to use it as instructed. We will conduct training sessions during the run-in period to insure this will not be a barrier for participants • Able to participate in a somewhat strenuous physical exercise program • Able to provide informed consent for participation in a research study	• History of depression, anxiety, or panic with medications started within last 3 mo (include if stable on medications) • Total cholesterol ≥240 mg/dL with low density lipoprotein cholesterol ≥190 mg/dL or triglyceride levels >300 mg/dL • Currently taking any of the following medications: hormone replacement therapy, beta blocker, allergy shots, or systematic corticosteroids (except inhalers) • Significant cardiovascular disease or disorders including but not limited to serious arrhythmias, cardiomyopathy, congestive heart failure, stroke or transient ischemic cerebral attacks, peripheral vascular disease with intermittent claudication, acute, chronic, or recurrent thrombophlebitis, and State II or III hypertension, myocardial infarction, and abnormal exercise stress test
	• Medical history with presence of significant conditions or disease that may interfere with study—eg, cancer within past 5 y of diagnosis (except nonmelanoma skin cancer), recent surgery • Pregnant or actively trying to become pregnant • Gave birth in last 12 mo or <6 mo postlactation
	• >90th percentile on the Brief Symptom Inventory
	• Planning to move from the area in the next 8 mo
	• Other medical, psychiatric, or behavioral factors that in the judgment of the principal investigator may interfere with study participation or the ability to follow the intervention protocol

Table 2 Measurement Sessions

	Baseline	3 mo	6 mo	Daily or weekly
Questionnaires asking about medical history and health-related, dietary, and physical activity behaviors	×	×	×	
Blood pressure	×			×
Weight	×			×
Waist and hip circumference	×	×	×	
Body scan to evaluate body composition and amount of fat (dual X-ray absorptiometry scan)	×	×	×	
Resting metabolic rate	×	×	×	
Graded exercise fitness test	×	×	×	
Fasting blood draw	×		×	
Download activity monitor data				×

over the study period. An orientation session included a presentation describing the study design and expectations for participation. Height and weight were measured to calculate BMI. Individuals wore the SenseWear Mini Armband® accelerometry device (Body Media Inc, Pittsburgh, PA) over a "run-in" period of 3 days to verify sedentary status (<7000 steps per day and ≤10 min of vigorous physical activity).[16]

Baseline Measurement Sessions

Baseline measurements consisted of 2 separate sessions within a period of 7 days. Baseline session 1 consisted of body composition assessment and a graded treadmill exercise test (modified Bruce test to volitional fatigue) to determine cardiorespiratory fitness. Resting blood pressure, weight, and height were measured, and a dual X-ray absorptiometry scan was performed. Baseline session 2

followed a 12-hour overnight fast. Resting metabolic rate (RMR) was measured. Individuals were given a SenseWear armband accelerometry device to measure activity over a period of 10 days.

Randomization

After completion of baseline measurements, individuals were stratified by age, sex, and race, and randomly assigned to either a moderate-exercise dose (MOD), a high-exercise dose (HIGH), or a nonexercise observation (OBS) group at a ratio of 3:3:1. Randomization was performed with computer-generated numbers.

Intervention

The intervention consisted of on-site, supervised treadmill exercise. Each participant was given an exercise prescription to achieve an intensity of 70% to 75% maximum heart rate. The target EEex was based on an intensity that allowed individuals to achieve the weekly EEex in a reasonable amount of time and number of training sessions.[17] To account for differences in body weight among individuals, each participant's prescribed dose of exercise was determined as weekly EEex per kilogram of body weight.[16] Assuming maximum aerobic capacity of approximately 8 METs in the study population,[18] the expected exercise intensity at 70% to 75% maximal capacity would be 5.8 METs (ie, 5.8 kcal/kg/h). Individuals in the MOD group were asked to achieve an EEex of 17.5 kcal/kg/wk, while the individuals in the HIGH group targeted an EEex of 35 kcal/kg/wk. In order to familiarize individuals with the treadmill and their required exercise volume, there was a ramp-up phase lasting 4 to 6 weeks during which individuals began with a weekly goal of 10 kcal/kg/wk and were ramped up to the prescribed dosage.

Exercise intensity was monitored by trained staff via a heart rate monitor (FT1™; Polar Electro, Lake Success, NY) and reviewed every 5 minutes. EEex from each exercise session was based on metabolic equations (treadmill walking $VO_2 = 3.5 + [0.1 \times \text{speed}] + [1.8 \times \text{speed} \times \%\text{grade}]$) and estimated using the individual's weight, duration, and speed/grade of the treadmill[19] so that prescribed exercise dosage for each session could be calculated prior to the participant's arrival.

All individuals were instructed to maintain their weight (within ±3% of their baseline body weight) throughout the 26-week intervention period. Nutritional consultation for the individuals was provided by a registered dietician. The OBS group came into the lab monthly to ensure weight maintenance. If weight was not within 3% of baseline body weight for a period of 2 consecutive weeks, individuals were required to meet with the staff registered dietician to discuss options to meet the study requirements. Individuals were removed from the study after 3 unsuccessful private sessions with the dietician, if body weight changed by more than 5%, or if 6 or more exercise sessions were missed in 1 month.

Measurements

All measurements were obtained by trained and certified research staff in the Clinical Exercise Research Center at the University of South Carolina.

Anthropometry and Body Composition

Anthropometric and body composition measurement techniques that were used have been described in detail previously.[20] Height (cm) and weight (kg) were measured using a wall-mounted stadiometer (Ayrton Crop, Prior Lake, MN) and an electronic scale (Healthometer, McCook, IL). The average of 2 measurements was used to calculate BMI (kg/m^2). Waist and hip circumference were measured using a spring-loaded tape measure. Fat mass and fat-free mass were measured with a Lunar Prodigy fan-beam dual X-ray absorptiometry scanner (model 8743; GE Healthcare, Waukesha, WI) and were analyzed using enCORE software (version 15; GE Healthcare, Boston, MA).

Resting Metabolic Rate

As described previously,[20] RMR was measured using standard indirect calorimetry under a ventilated hood (TrueOne 2400; Parvo Medics, Sandy, UT) over a 30-minute period with data collection over the last 15 minutes. Individuals tested in the morning in a 12-hour fasted state and at least 24 hours following the last bout of exercise.

Energy Expenditure

Each participant was issued a SenseWear armband to monitor physical activity over a measurement period of 10 days at baseline, 13 weeks, and 26 weeks. Individuals were instructed to wear the armband for 24 hours, excluding wet activities such as showering or swimming. Individuals were asked to maintain a journal of activities during periods of time when the armband was not worn. Energy expenditure during armband wear time was estimated for each participant using the SenseWear armband algorithm with the individual's measured RMR substituted for the standard 1 kcal/kg/h used in the SenseWear algorithm. This method of estimation using the armband has been shown to provide an accurate estimation of energy expenditure in free-living adults.[21] Energy expenditure during nonwear time was estimated based on matching the activity recorded in the activity journal with the corresponding MET value according to the 2011 Compendium of Physical Activities.[22] Energy expenditure for such periods was calculated as the MET value of the activity (MET minutes) times the individual's measured RMR.[20] TDEE was calculated as energy expenditure during wear time plus energy expenditure during nonwear time. EEex calculations were based on metabolic equations and estimated using the individual's weight, duration, and speed/grade of the treadmill.[19]

Energy Intake

Energy intake was calculated from data collected over the 10-day measurement period based on the energy balance equation represented as: $\Delta ES = EI - EE$, where ES represents change in energy stores, EI represents the rate of energy intake, and EE represents the rate of energy expenditure. Energy intake was calculated using estimated energy stores derived from the dual X-ray absorptiometry scan-based fat mass and fat-free mass ($1020 \frac{\Delta FFM}{\Delta t} + 9500 \frac{\Delta FM}{\Delta t}$), and energy expenditure derived from the armband accelerometer. Energy intake was calculated as follows: Calculated energy intake = $1020 \frac{\Delta FFM}{\Delta t} + 9500 \frac{\Delta FM}{\Delta t} + EE$, where ΔFFM and ΔFM represent the changes in fat-free mass and fat mass.[21] The energy densities of fat-free mass and fat mass are estimated at 1020 and 9500 kcal/kg, respectively.[23]

Statistical Analyses

Frequencies and distributions were calculated with IBM SPSS Statistics (version 25; IBM, Armonk, NY). Sample size

calculations were performed with Sealed Envelope Power Calculator (version 2011; Sealed Envelope Ltd, London, UK) for a 2-sided analysis of variance designed to achieve a power of 0.80 at α level of .05. Calculations based on increases in mean TDEE for the 2 exercise groups of at least 175 (100) kcal/d and 50 kcal/d for the OBS group indicated a need for at least 11 individuals per group to detect a difference over 26 weeks between OBS and the exercise groups. With a potentially high dropout rate and partial compliance of 30% among the exercise groups, randomization was structured for a 1:3:3 distribution of at least 15:45:45 individuals in OBS, MOD, and HIGH groups, respectively. Statistical significance for comparison of 26-week changes among groups was tested using analysis of variance for continuous variables and chi-square tests for categorical variables (race and sex). The Tukey post hoc test was used to identify differences between specific groups. Results are described as group mean (SD) unless indicated. Results illustrated in figures are described as group mean (SE) adjusted for age, race, and sex unless otherwise indicated. All reported P values are 2-sided with significance set at $P < .05$.

Results

Individuals and Randomization

As described in Figure 1, 115 individuals completed orientation sessions and were randomized into the OBS, MOD, and HIGH groups (n = 16, n = 49, and n = 50, respectively). Eighty-one individuals (70%) completed the 26-week intervention period. Postintervention, 8 individuals' data were removed because they did not reach a threshold of 75% compliance to the assigned weekly EEex with 13 individuals removed for failing to maintain body weight. Therefore, 60 individuals (52%) were included in the data analysis with a distribution among groups of OBS = 13, MOD = 26, and HIGH = 21. The demographic distribution of the individuals who withdrew was as follows: OBS group, 2 females and 1 male; MOD group, 2 females and 5 males; and HIGH group, 5 females and 6 males. There were no significant demographic, anthropometric, or energetic differences between the baseline data of the individuals included in the analyses and those individuals not included.

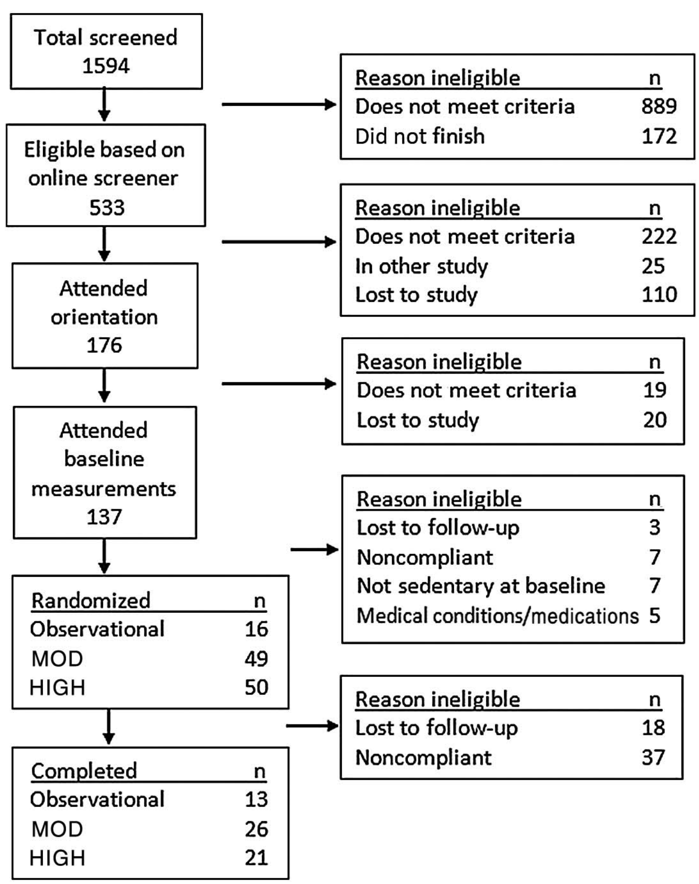

Figure 1 — Diagram illustrating the participant flow, inclusion, and exclusion.

The mean age for the individuals was 30.3 (7.3) years with 30 females (50%) and 30 males (50%). Almost half of the individuals were white (46.7%), followed by black (33.3%) and Asian (18.3%) individuals. Table 3 shows baseline characteristics among the 3 groups. There were no significant differences in age, sex, or race among the randomized groups.

Anthropometry

Forty-nine (82%) individuals who completed the study were classified as overweight (25 kg/m^2 ≤ BMI ≤ 30 kg/m^2) at baseline with the remaining individuals classified as obese (BMI > 30 kg/m^2). The mean height, weight, and waist circumference for the group were 168.9 (9.5) cm, 79.9 (11.66) kg, and 85.6 (9.4) cm, respectively, with a mean BMI of 27.92 (2.6) kg/m^2. The average baseline body fat percentage was 29.57 (4.59) for men and 39.57 (3.96) for women (Table 3).

As reported in Table 4, there was no significant difference in weight change by group assignment ($F_{2,57} = 0.988$, $P = .379$, $\eta^2_p = .051$) or among male participants ($F_{2,27} = 0.379$, $P = .689$, $\eta^2_p = .015$). Females in the HIGH group showed loss of body weight (−0.83 [1.48] kg) compared with OBS (0.59 [0.56] kg, $P = .028$) but not MOD group (0.89 [0.84] kg, $P = .548$) ($F_{2,27} = 4.058$, $P = .029$, $\eta^2_p = .029$).

There were no significant changes by group in fat-free mass or fat mass (Table 4). There was a nonstatistically significant finding ($F_{2,57} = 3.043$, $P = .056$, $\eta^2_p = .096$) for a group main effect of exercise participation on body fat percentage change. Females showed a group effect with a stepwise reduction in body fat percentage ($F_{2,27} = 5.922$, $P = .007$, $\eta^2_p = .305$). There was nonstatistically significant evidence for a group by sex effect for change in fat mass ($F_{2,54} = 3.141$, $P = .051$, $\eta^2_p = .104$) with females showing a stepwise decrease from OBS to HIGH ($F_{2,27} = 6.776$, $P = .004$). Males showed no reduction in fat mass ($F_{2,27} = 0.005$, $P = .995$, $\eta^2_p = .027$) or body fat percentage ($F_{2,27} = 0.167$, $P = .847$, $\eta^2_p = .012$). There was no group by sex effect for change in fat-free mass ($F_{2,58} = 0.186$, $P = .830$, $\eta^2_p = .003$). There was no difference in between-group ($F_{2,55} = 0.335$, $P = .717$, $\eta^2_p = .012$) or group by sex interaction for change in waist circumference ($F_{2,58} = 0.721$, $P = .491$, $\eta^2_p = .027$). It is important to note that the study was not powered statistically to test an effect of sex, so these findings are meant to be strictly exploratory.

Energy Expenditure and Activity

The compliance percentage to the prescribed exercise program was not different between the MOD (84.9 [12.4]) and HIGH (81.9 [36.9]) groups ($F_{1,45} = 0.153$, $P = .698$, $\eta^2_p = .003$). There was a highly significant stepwise increase from OBS to HIGH

Table 3 Baseline Characteristics by Group

Group assignment	Observational (n = 13)	MOD (n = 26)	HIGH (n = 21)
Age, y	29.9 (6.9)	30.5 (7.2)	30.6 (8.1)
%Male	46	50	57
%White	54	39	49
Height, cm	169.6 (7.2)	167.5 (9.6)	170.5 (10.6)
Body weight, kg	81.6 (10.4)	78.8 (10.9)	80.5 (13.5)
Body mass index, kg/m^2	28.3 (2.9)	28.0 (2.5)	27.5 (2.6)
Waist circumference, cm	86.5 (9.8)	85.2 (8.9)	85.6 (10.2)
Fat mass, kg	28.9 (5.6)	28.1 (6.0)	26.6 (6.5)
Fat-free mass, kg	53.9 (8.1)	51.4 (8.8)	54.0 (11.9)
Body fat, %	34.5 (7.6)	35.9 (7.8)	33.0 (9.1)
VO_2peak, mL/kg/min	28.8 (6.4)	26.8 (6.4)	31.6 (7.8)
Resting metabolic rate, kcal/d	1526 (191)	1409 (264)	1520 (316)
Total daily energy expenditure, kcal/d	2570 (460)	2484 (397)	2550 (464)
Total energy stores, kcal	329,731 (53,798)	318,884 (57,968)	307,970 (61,029)

Note: There were no significant differences ($P < .05$) in any variable among groups.

Table 4 Baseline to 26-Week Changes by Group

Group assignment	Observational	MOD	HIGH	Significance (*P* value)
Body weight, kg	0.08 (0.95)	−0.42 (1.33)	−0.62 (1.73)	.379
Body mass index, kg/m^2	0.03 (0.35)	−0.23 (0.48)	−0.21 (0.53)	.256
Waist circumference, cm	−0.69 (4.1)	−0.5 (7.5)	−1.86 (3.9)	.717
Fat mass, kg	0.05 (1.22)	−0.45 (1.36)	−1.04 (1.55)	.122
Fat-free mass, kg	−0.17 (1.14)	0.22 (1.21)	0.56 (1.45)	.278
Body fat percent	0.05 (1.22)	−0.53 (1.39)	−1.15 (1.49)*	.056
Resting metabolic rate, kcal/d	19 (87)	2 (152)	3 (169)	.290
Exercise time, min/wk	0 (0)	159.5 (26.9)*	223.2 (59.1)*,**	<.001
Exercise energy expenditure, kcal/kg/wk	0 (0)	16 (2)*	27 (5)*,**	<.001

*Versus observational group <.01. **Versus MOD group <.05.

in EEex during the intervention period, as measured in total kcal/d ($F_{2,57} = 205.88$, $P < .001$, $\eta_p^2 = .878$) or by kcal/kg/d ($F_{2,57} = 367.353$, $P < .001$, $\eta_p^2 = .913$) (Table 4 and Figure 2). The exercise intervention for the MOD group increased mean energy expenditure by 161 (27) kcal/d or about a 15% increase in activity-related energy expenditure. For the HIGH group, the increase of about 277 (58) kcal/d represented an increase in activity-related energy expenditure of about 27%. TDEE at baseline was not different among the 3 randomized groups (Figure 2). In contrast to the changes in EEex, there was no significant group effect on the change in TDEE over the intervention period ($F_{2,57} = 2.219$, $P = .118$, $\eta_p^2 = .072$).

Energy Intake

Change in calculated daily energy intake (Table 4 and Figure 2) indicates that there was no significant difference between groups during the intervention ($F_{2,57} = 1.603$, $P = .211$, $\eta_p^2 = .053$). Similarly, there was no significant group effect among females ($F_{2,27} = 2.010$, $P = .154$, $\eta_p^2 = .130$) or males ($F_{2,27} = 0.304$, $P = .741$, $\eta_p^2 = .022$) (Figure 3).

Energy Stores

Table 3 shows the baseline energy stores with no between-group differences. There was no significant difference between groups for the change in energy stores ($F_{2,57} = 1.911$, $P = .157$, $\eta_p^2 = .063$; Figure 2). Male and female individuals showed a sex difference in change in energy stores ($F_{2,27} = 6.771$, $P = .004$, $\eta_p^2 = .142$; Figure 3). Males showed no between-group differences in total kilocalories changes ($P = .976$) while females in the 2 exercise groups showed a stepwise decrease in total energy stores from the change in the OBS group (OBS vs MOD and HIGH group, $P = .004$; MOD vs HIGH group, $P = .030$).

Resting Metabolic Rate

There were no differences in RMR among groups at baseline ($F_{2,56} = 1.114$, $P = .335$; Table 3), or within- or between-group changes in RMR during the training period ($F_{2,56} = 0.070$, $P = .932$, $\eta_p^2 = .002$; Table 4). Furthermore, there were no differences among groups for the change in RMR for female ($F_{2,27} = 0.040$, $P = .960$, $\eta_p^2 = .003$) or male individuals ($F_{2,27} = 0.027$, $P = .974$, $\eta_p^2 = .022$).

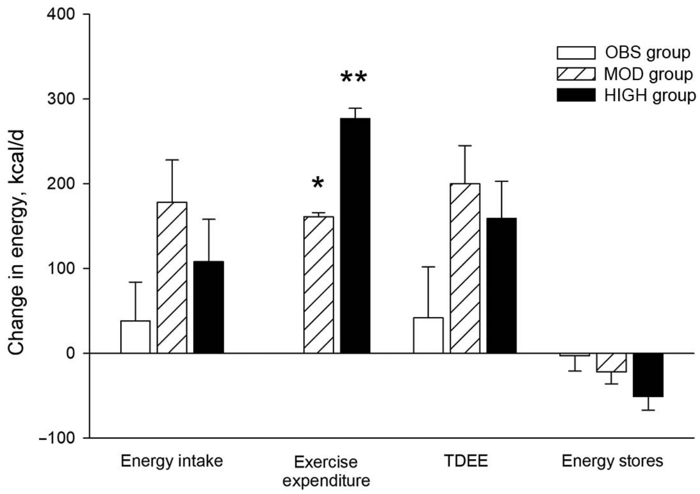

Figure 2 — Graph illustrating group changes in daily energy dynamics among randomized groups. Data are presented as mean (SE) adjusted for age, race, and sex. *Versus OBS group. **Versus MOD group. $P < .05$. HIGH indicates high exercise; MOD, moderate exercise; OBS, observation; TDEE, total daily energy expenditure.

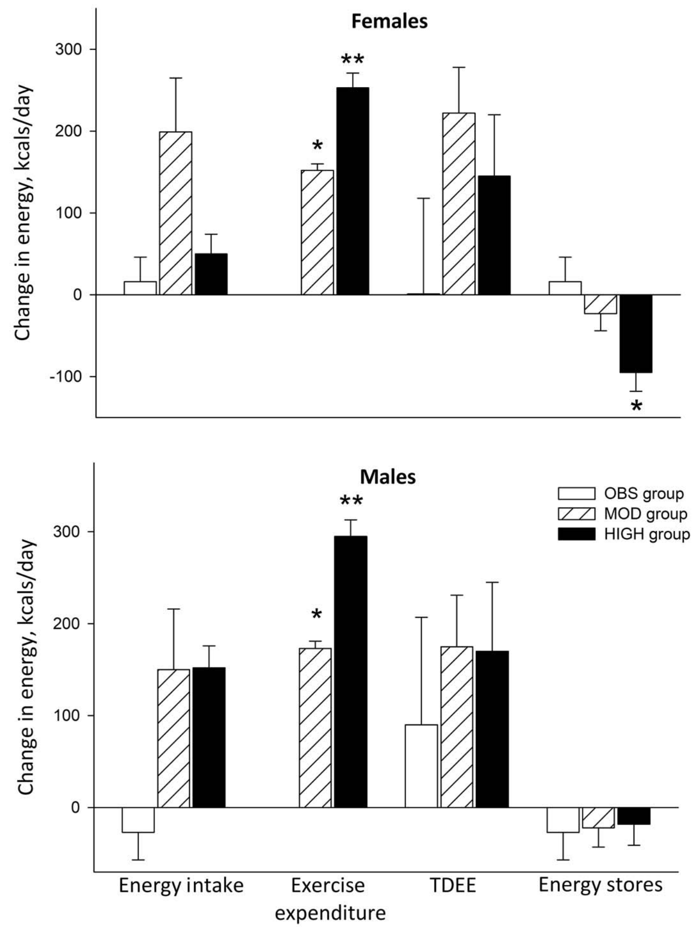

Figure 3 — Graph illustrating group changes in daily energy dynamics for females and males. Data are presented as mean (SE) adjusted for age, race, and sex. *Versus OBS group. **Versus MOD group. $P < .05$. MOD indicates moderate exercise; OBS, observation; TDEE, total daily energy expenditure.

Discussion

The most important findings from the current study are (1) the stepwise increase in exercise-induced energy expenditure across groups did not result in an equivalent increase in TDEE; (2) in contrast to the similar increase of EEex and TDEE among the individuals in the MOD group, the increase in TDEE among the individuals in the HIGH group was lower than the achieved daily average of EEex; and (3) while all individuals included in the analyses maintained body weight within 3% of baseline measurements, female individuals in the HIGH group lost more body weight than those in the OBS or MOD groups, and the weight loss was entirely due to a loss of fat mass.

Body Composition and Metabolic Function

The primary focus of most research examining the energetics of body weight change has been based on the anorexic effects of increased expenditure through exercise and reduced consumption through dieting and caloric restriction. In one earlier weight management study, individuals were randomized to a group that increased energy expenditure through exercise with compensated intake to maintain body weight (attempting to maintain energy balance at a higher energy flux) resulting in significant loss of abdominal fat without overall body weight change.[15] Similarly, the present study showed a stepwise reduction in fat mass among the women in the 2 exercise groups—but not among the men. Previous small studies showed similar effects in individuals who reduced overall fat mass, but not abdominal fat, by increasing energy expenditure through exercise while maintaining body weight.[24] While women individuals in the current study did not lose fat specifically in the torso, the loss of fat mass resulting from increased energy expenditure appears to be consistent across the literature.[25]

In the present study, the changes in body fat among women in the HIGH group explain the reduction in total energy stores during the intervention period. This group experienced a similar change in TDEE to that of the MOD group of females—suggesting that the loss of fat mass was specific to the EEex rather than TDEE changes. Importantly, the reduction in energy stores was not due to a change in RMR, as there was no difference from baseline RMR levels.

As RMR is dependent on total body mass and fat-free mass, a significant rise in either will increase RMR.[26] Generally, studies indicate that there is a strong relationship between physical activity and RMR across a range of exercise intensities, and that EEex is associated positively with fat-free mass and increased RMR.[27] As discussed previously,[28] the positive relationship between high-energy flux and RMR does not explain risk of weight gain at a low-energy flux. Results from the present study suggest that there is a complex relationship among RMR, energy expenditure from physical activity and TDEE.

Energy Balance and Compensation

A longstanding question is whether increasing structured exercise will result in an increase in TDEE—and if so, whether the increases are proportional.[29] Previous studies in the older adults have shown no increase in TDEE with adoption of a structured exercise program and concluded that the incongruity was due to a reduction in nonstructural physical activity.[8–10] In contrast, studies in young adults reported that nonstructured physical activity actually increased with an increase in exercise activity.[11–13]

The exercising groups in the present study showed a clear stepwise increase in structured EEex compared with the OBS group, with the HIGH group reaching an expenditure of almost 300 kcal/d. However, TDEE among the MOD and HIGH groups did not respond similarly as there was no significant difference in the change compared across the 3 groups. The change in TDEE for the MOD group was about 24% greater than the daily EEex. By contrast, the change in TDEE recorded for the HIGH group was only about 57% of their EEex. These data suggest an increase in daily non-EEex among the individuals in the MOD group with a decrease among individuals in the HIGH group—a compensatory response that would impact the accuracy of weight loss models based on the assumption that TDEE increases proportionally to EEex.

While studies support the relationship between physical activity and better weight management, exercise typically results in high variability in weight change and generally less actual body weight loss than predicted.[1,30] The most-cited explanations are compensatory increases in energy intake and/or reductions in nonintentional activity.[9,31] An analysis of 15 exercise training studies concluded that factors limiting weight loss were dietary compensation and low dose of achieved EEex (in contrast to prescribed EEex).[32]

To address the confounding variability in eating behavior during exercise interventions, the present study required that individuals maintain body weight by matching energy intake with any change in energy expenditure. The balanced relationship between increased energy intake and expenditure was generally achieved in males in both exercising groups and females in the MOD group. The stable energy stores among the male and female participants in the MOD group indicate that the increase in TDEE was matched relatively well through increased energy intake, which was required by study design.

In contrast to the individuals in the MOD group, the introduction of a substantially greater amount of EEex in the HIGH group resulted in a TDEE of less than what would be expected if energy expenditures were additive. The males in the HIGH group increased TDEE only about 60% of what would be expected with a proportional change to the increased EEex—resulting in similar TDEEs for the males in the MOD and HIGH groups.

The effect of exercise training on TDEE among females in the HIGH group was also less (about 57%) than anticipated from a proportional response. In fact, the mean absolute TDEE for the individuals in the HIGH group was about 35% lower than that of the MOD group. The females in the HIGH group lost significant energy stores through a loss in fat mass. Since there was no change in RMR among these individuals, this loss of energy stores was likely a result of a proportionally lower energy intake compared with expenditure.

Since caloric intake was structured to maintain body weight, it could be speculated that an EEex threshold had been exceeded by the HIGH group above which compensation began to play a significant role in blunting the rise in TDEE. If so, the threshold does not appear to be sex specific as both females and males in the MOD group could maintain energy balance in the higher energy state, but neither sex in the HIGH group could maintain a proportional change in TDEE above that observed in the MOD group. The sex difference appeared to be in the ability of the males in the HIGH group to maintain a high EEex with an increase in energy intake, while the females in this exercise group showed an inability to maintain the EEex without a significant reduction in energy stores.

There are a number of limitations to the study. First, the individuals were limited to healthy young adults who were overweight or obese. So, it is unclear if the results can be generalized to other age groups or healthy weight populations. Second, the exercise intensity (70%–75% of peak capacity) was chosen to allow for the allotted weekly EEex in a reasonable number of sessions. However, the intensity is above the typical "moderate" intensity range of 50% to 65% of maximal aerobic capacity. Third, the individuals in the HIGH group had difficulty in achieving the prescribed EEex as reflected by the greater dropout rate and group's average EEex below 35 kcal/kg/wk. Fourth, differences found between female and male participants should be considered with caution as the study was not powered statistically to compare sexes. Fifth, the requirement to maintain body weight produced an artificial influence on eating behavior that should not be perceived as a normal dietary response to exercise.

Conclusions

The results of this study suggest that increasing physical activity–associated energy expenditure does not necessarily translate to a proportional increase in TDEE. Since the increase in TDEE for the MOD group was about 6%, and that for the HIGH group was about 11%, compensatory mechanisms may become a factor in the 8% to 10% range of TDEE. The findings suggest that an emphasis should be placed on maintaining or increasing non-EEex when prescribing exercise interventions.

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References

1. Thorogood A, Mottillo S, Shimony A, et al. Isolated aerobic exercise and weight loss: a systematic review and meta-analysis of randomized controlled trials. *Am J Med*. 2011;124(8):747–755. PubMed ID: 21787904 doi:10.1016/j.amjmed.2011.02.037
2. Dhurandhar EJ, Kaiser KA, Dawson JA, Alcorn AS, Keating KD, Allison DB. Predicting adult weight change in the real world: a systematic review and meta-analysis accounting for compensatory changes in energy intake or expenditure. *Int J Obes*. 2015;39(8): 1181–1187. doi:10.1038/ijo.2014.184
3. King NA, Caudwell P, Hopkins M, et al. Metabolic and behavioral compensatory responses to exercise interventions: barriers to weight loss. *Obesity*. 2007;15(6):1373–1383.

4. Schwiertz A, Taras D, Schafer K, et al. Microbiota and SCFA in lean and overweight healthy subjects. *Obesity*. 2010;18(1):190–195. doi:10.1038/oby.2009.167
5. Drapeau V, King N, Hetherington M, Doucet E, Blundell J, Tremblay A. Appetite sensations and satiety quotient: predictors of energy intake and weight loss. *Appetite*. 2007;48(2):159–166. PubMed ID: 17045700 doi:10.1016/j.appet.2006.08.002
6. Colley RC, Hills AP, King NA, Byrne NM. Exercise-induced energy expenditure: implications for exercise prescription and obesity. *Patient Educ Couns*. 2010;79(3):327–332. PubMed ID: 20392589 doi:10.1016/j.pec.2010.03.001
7. Hume DJ, Yokum S, Stice E. Low energy intake plus low energy expenditure (low energy flux), not energy surfeit, predicts future body fat gain. *Am J Clin Nutr*. 2016;103(6):1389–1396. PubMed ID: 27169833 doi:10.3945/ajcn.115.127753
8. Goran MI, Poehlman ET. Endurance training does not enhance total energy expenditure in healthy elderly persons. *Am J Physiol*. 1992; 263(5, pt 1):E950–E957. PubMed ID: 1443128
9. Meijer EP, Westerterp KR, Verstappen FT. Effect of exercise training on total daily physical activity in elderly humans. *Eur J Appl Physiol Occup Physiol*. 1999;80(1):16–21. PubMed ID: 10367718 doi:10.1007/s004210050552
10. Morio B, Montaurier C, Pickering G, et al. Effects of 14 weeks of progressive endurance training on energy expenditure in elderly people. *Br J Nutr*. 1998;80(6):511–519. PubMed ID: 10211049 doi:10.1017/S0007114598001603
11. McLaughlin R, Malkova D, Nimmo MA. Spontaneous activity responses to exercise in males and females. *Eur J Clin Nutr*. 2006; 60(9):1055–1061. PubMed ID: 16493451 doi:10.1038/sj.ejcn.1602417
12. Hollowell RP, Willis LH, Slentz CA, Topping JD, Bhakpar M, Kraus WE. Effects of exercise training amount on physical activity energy expenditure. *Med Sci Sports Exerc*. 2009;41(8):1640–1645. PubMed ID: 19568195 doi:10.1249/MSS.0b013e31819c71a4
13. Turner JE, Markovitch D, Betts JA, Thompson D. Nonprescribed physical activity energy expenditure is maintained with structured exercise and implicates a compensatory increase in energy intake. *Am J Clin Nutr*. 2010;92(5):1009–1016. PubMed ID: 20826629 doi:10.3945/ajcn.2010.29471
14. Duncan GE, Perri MG, Theriaque DW, Hutson AD, Eckel RH, Stacpoole PW. Exercise training, without weight loss, increases insulin sensitivity and postheparin plasma lipase activity in previously sedentary adults. *Diabetes Care*. 2003;26(3):557–562. PubMed ID: 12610001 doi:10.2337/diacare.26.3.557
15. Ross R, Dagnone D, Jones PJ, et al. Reduction in obesity and related comorbid conditions after diet-induced weight loss or exercise-induced weight loss in men: a randomized, controlled trial. *Ann Intern Med*. 2000;133(2):92–103.
16. Church TS, Earnest CP, Skinner JS, Blair SN. Effects of different doses of physical activity on cardiorespiratory fitness among sedentary, overweight or obese postmenopausal women with elevated blood pressure: a randomized controlled trial. *JAMA*. 2007; 297(19):2081–2091. PubMed ID: 17507344 doi:10.1001/jama.297.19.2081
17. Donnelly JE, Blair SN, Jakicic JM, et al. American College of Sports Medicine Position Stand. Appropriate physical activity intervention strategies for weight loss and prevention of weight regain for adults. *Med Sci Sports Exerc*. 2009;41(2):459–471. PubMed ID: 19127177 doi:10.1249/MSS.0b013e3181949333
18. Wang CY, Haskell WL, Farrell SW, et al. Cardiorespiratory fitness levels among US adults 20–49 years of age: findings from the 1999–2004 National Health and Nutrition Examination Survey. *Am J Epidemiol*. 2010;171(4):426–435. PubMed ID: 20080809 doi:10.1093/aje/kwp412
19. Riebe D, ed. *ACSM's Guidelines for Exercise Testing and Prescription*. 10th ed. Philadelphia, PA: Wolters Kluwer; 2018.
20. Hand GA, Shook RP, Paluch AE, et al. The energy balance study: the design and baseline results for a longitudinal study of energy balance. *Res Q Exerc Sport*. 2013;84(3):275–286. PubMed ID: 24261006 doi:10.1080/02701367.2013.816224
21. Shook RP, Hand GA, O'Connor DP, et al. Energy intake derived from an energy balance equation, validated activity monitors, and dual X-ray absorptiometry can provide acceptable caloric intake data among young adults. *J Nutr*. 2018;148(3):490–496. PubMed ID: 29546294 doi:10.1093/jn/nxx029
22. Ainsworth BE, Haskell WL, Herrmann SD, et al. 2011 compendium of physical activities: a second update of codes and MET values. *Med Sci Sports Exerc*. 2011;43(8):1575–1581.
23. Thomas DM, Schoeller DA, Redman LA, Martin CK, Levine JA, Heymsfield SB. A computational model to determine energy intake during weight loss. *Am J Clin Nutr*. 2010;92(6):1326–1331. PubMed ID: 20962159 doi:10.3945/ajcn.2010.29687
24. Ross R, Janssen I, Dawson J, et al. Exercise-induced reduction in obesity and insulin resistance in women: a randomized controlled trial. *Obes Res*. 2004;12(5):789–798. PubMed ID: 15166299 doi:10.1038/oby.2004.95
25. Lee S, Kuk JL, Katzmarzyk PT, Blair SN, Church TS, Ross R. Cardiorespiratory fitness attenuates metabolic risk independent of abdominal subcutaneous and visceral fat in men. *Diabetes Care*. 2005;28(4):895–901. PubMed ID: 15793192 doi:10.2337/diacare.28.4.895
26. Stiegler P, Cunliffe A. The role of diet and exercise for the maintenance of fat-free mass and resting metabolic rate during weight loss. *Sports Med*. 2006;36(3):239–262. PubMed ID: 16526835 doi:10.2165/00007256-200636030-00005
27. Speakman JR, Selman C. Physical activity and resting metabolic rate. *Proc Nutr Soc*. 2003;62(3):621–634. PubMed ID: 14692598 doi:10.1079/PNS2003282
28. Hand GA, Shook RP, Hill JO, Giacobbi PR, Blair SN. Energy flux: staying in energy balance at a high level is necessary to prevent weight gain for most people. *Expert Rev Endocrinol Metab*. 2015; 10(6):599–605. PubMed ID: 30289030 doi:10.1586/17446651.2015.1079483
29. Washburn RA, Lambourne K, Szabo AN, Herrmann SD, Honas JJ, Donnelly JE. Does increased prescribed exercise alter non-exercise physical activity/energy expenditure in healthy adults? A systematic review. *Clin Obes*. 2014;4(1):1–20. PubMed ID: 25425128 doi:10.1111/cob.12040
30. King NA, Hopkins M, Caudwell P, Stubbs RJ, Blundell JE. Individual variability following 12 weeks of supervised exercise: identification and characterization of compensation for exercise-induced weight loss. *Int J Obes*. 2008;32(1):177–184. doi:10.1038/sj.ijo.0803712
31. King NA, Caudwell PP, Hopkins M, Stubbs JR, Naslund E, Blundell JE. Dual-process action of exercise on appetite control: increase in orexigenic drive but improvement in meal-induced satiety. *Am J Clin Nutr*. 2009;90(4):921–927. PubMed ID: 19675105 doi:10.3945/ajcn.2009.27706
32. Thomas DM, Bouchard C, Church T, et al. Why do individuals not lose more weight from an exercise intervention at a defined dose? An energy balance analysis. *Obes Rev*. 2012;13(10):835–847. PubMed ID: 22681398 doi:10.1111/j.1467-789X.2012.01012.x